

Geomorphic processes and remote sensing signatures of alluvial fans in the Kun Lun Mountains, China

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Abstract

Remote sensing techniques may be used to assist in regional mapping of geomorphic units related to past climate changes through their sensitivity to roughness and composition. Radar images from the Spaceborne Radar Laboratory and visible-wavelength images from the French SPOT satellite were used to determine remote sensing signatures of alluvial fan units for an area in the Kun Lun Mountains of northwestern China. These data were then used, with field observations, to compare surface processes and their effects on remote sensing signatures in northwestern China and the southwest U. S. Geomorphic processes affecting alluvial fans in the Kun Lun Mountains of western China include aeolian deposition, desert varnish, and fluvial dissection. However, salt weathering is a much more important process in the Kun Lun than in the southwest U.S. This decreases the effectiveness of desert varnish and prevents desert pavement from forming. Thus, the Kun Lun signatures are diagnostic of the dominance of salt weathering while signatures from the southwest U.S. are indicative of the dominance of desert varnish and pavement processes. Remote sensing signatures are consistent enough in these two regions to be used for mapping fan units over large areas.

Introduction

The impact of Quarternary climatic fluctuations on sedimentation, surficial modification processes, and soil development on desert piedmonts has been recognized for some time [Laynes, 1965; Melton, 1965; Bull and Schick, 1979; Pontieri et al., 1980; Wells et al., 1984; Christenson and Purcell, 1985; McFadden and Hendricks, 1985; Machette, 1985; Ponti, 1985; Wells et al., 1985; Dohrenwend et al., 1986; Smith, 1994]. Temporal relationships between climate changes in the western U.S. and their effects have been established through relative-age criteria such as the areal coverage and thickness of rock coatings [Dorn and Oberlander, 1982; Farr and Adarns, 1984], morphostratigraphic relations with other Quarternary units [Wells et al., 1984; Christenson and Purcell, 1985; Ritter et al., 1995], and the stage of landscape evolution represented by the thickness of aeolian mantles, extent of desert pavement, maturity of soil profiles, and density of drainages [Dohrenwend et al., 1987; McFadden and Weldon, 1987; McFadden et al., 1986; McFadden et al., 1987; Wells et al., 1985]. These relative-age criteria have also been used as the basis for correlation of alluvial deposits between widely separated areas in the southwestern U.S. [Pontieri et al., 1980; Christenson and Purcell, 1985; Ponti, 1985] leading to the supposition that there may have been a number of regional depositional events in the western U. S., the deposits of which are now preserved in arid areas [e.g. Bull, 1991; Dohrenwend et al., 1991].

Many relative-age criteria can be detected with remote sensing techniques. indeed, aerial photography has been used to delineate alluvial fan units based on drainage morphology and desert varnish development [Christenson and Purcell, 1985], however more sophisticated remote sensing techniques may be used in conjunction with air photos to better define surface composition and morphology. in addition, orbital remote sensing techniques may be more efficient for mapping large regions and may be the only source of mapping information for some areas. For example: Using a combination of Seasat radar and Landsat visible-near infrared images, Farr and Evans [1992] were able to map alluvial fan units in Death Valley and adjacent basins because the radar is sensitive to surface roughness variations caused by desert pavement formation and because the Landsat Thematic Mapper (TM) is sensitive to surface composition changes brought about by the development of desert varnish coatings. Similarly, Gillespie et al. [1984] were able to map the same area with the airborne Thermal infrared Multi spectral Scanner (Tl MS) because it is sensitive to desert varnish and to compositional changes as physical weathering processes concentrate resistant lithologies. Other work has shown that relative ages of piedmont surfaces can be mapped with remote sensing techniques on the basis of surface roughness changes brought about by physical weathering and aeolian deposition [Farr and Gillespie, 1984; Arvidson et al., 1993], iron oxide and soil development [Gillespie et al., 1986], and vegetation density [Ustin et al., 1986]. Numerical ages, available at several sites in the southwest U. S., have allowed derivations of the rates of some of these processes; for example, radiometric dates of lava flows at the Cima volcanic field [Dohrenwend et al., 1984] allowed the rate of

surface roughness modification of the flows by aeolian deposition to be derived [Farr, 1992].

This paper describes the use of radar images from the Spaceborne Radar Laboratory and visible-near infrared images from the Landsat MSS and French SPOT satellites to determine signatures of fan units and to generate maps of relative ages for an area in the Kun Lun Mountains of northwestern China (Fig. 1). These data were then used, with field observations, to compare surface processes and climate change chronologies between northwestern China and the southwest U.S.

Remote Sensing

The Space Radar Laboratory collected a number of swaths over western China. Data-take 175.31 from the first flight covered the alluvial fans of the Karakax Valley (Fig. 2a). This was a dual-polarization swath (HH 1, HV); X-SAR had already been shut down by the time of this data-take, so no X-band data are available for this data take. In addition to the radar data, French SPOT (panchromatic visible, 10 m resolution, Fig. 2b) and Landsat MSS (4 visible-near infrared bands, 80 m resolution) images were used to define signatures in the visible and near infrared part of the spectrum.

As discussed above, radar and visible-near infrared images can be used to detect the signatures of geomorphic processes and to determine relative ages of surfaces. The processes at work on the fans of the Karakax Valley have produced clear signals that are consistent up and down the valley. Figure 3a shows mean uncalibrated brightness levels for 3 distinct units on several fans in the Karakax Valley. These units were recognized by their relative elevation, degree of dissection, and relation to the active stream channel. There is a clear and steady decrease in radar brightness with increasing age and a steady increase in brightness in the SPOT image with age.

The signatures for the Karakax Valley fans may be compared with those from the western U. S., where the types, rates, and magnitudes of the processes that produced the signatures are relatively well known. Remote sensing signatures of surfaces in Death Valley in the southern Great Basin of the U.S. show an abrupt decrease in radar brightness for very old surfaces and a steady decrease in visible-near infrared brightness with increasing age [Farr and Evans, 1992; Fig. 3b]. The radar-roughness signature is a result of the lack of significant physical weathering of rocks on the active and intermediate units and the presence of a thick aeolian mantle topped by a stone pavement on the oldest units. The visible-near infrared signature is caused by the development of desert varnish, which increases its areal coverage and thickness on resistant rock types continuously with time. The aeolian deposits, while increasing in thickness with time, are always covered by the resistant lag, which is well-varnished.

In order to determine the cause of the different remote sensing signatures, and to assess the relative importance of different modification processes on the surfaces of the Karakax Valley fans, field observations and measurements were made on the

different units. These included rock type distribution, rock/silt coverage, rock relief, desert varnish development, color, and local topography.

Geomorphology

The Karakax Valley is controlled by the Altyn Tagh fault, a long left-lateral strike-slip fault running from the Qilian Shan in the east to the Karakoram fault in the west [Peltzer et al., 1989]. The valley, at 3600-4000 m elevation, currently is arid with almost no vegetation, except along the river in its bottom and along a few lateral streams fed by glaciers above. Strong winds from the northeast have scoured the valley, producing numerous ventifacts and depositing silt. Thick loess deposits are found at lower elevations in valleys to the north and in the Tarim Basin.

Rock types in the mountains bounding the valley consist mainly of metasedimentary and plutonic rocks. The major alluvial fans on the north side of the valley lie at the mouths of the larger drainage basins, all of which have high relief (about 1700 m), topped by small to moderate sized glaciers.

There are 3 well-defined alluvial fan units in the Karakax Valley. The oldest units are typically highest and dissected by the younger. In some cases, younger units are entrenched into the older and deposited at the distal end of the fan (e.g. telescoped), but in others, the younger units are deposited to the side of the older units.

The youngest fan unit includes active and very recently active surfaces composed of fresh cobbles and boulders derived from the mountains above (Fig. 4a). The rocks on this unit are a mix of coarse-grained siliceous granitic (20-30%) and fine-grained mafic and metamorphic (70-80%) rock types. The rocks are fresh, with a slight staining of desert varnish on the less recently active surfaces. Rocks cover about 50-80% of the surface, with rock relief ranging up to 35 cm. Larger-scale relief is present on some active surfaces in the form of swales oriented down-slope, having a wavelength of about 3-8 m and an amplitude of about 50 cm.

Standing about 3 m above the active units, an intermediate fan unit can be mapped based on its bouldery surface and the presence of desert varnish on the more resistant boulders (Fig. 4b). In addition, on many of the surfaces, the coarse-grained granitic rocks are heavily salt-weathered, yielding a variety of tafoni and beveled remnants of former boulders. Resistant fine-grained mafic and metamorphic rocks make up about 80% of the rock population, the rest being coarse-grained siliceous granitic rocks. Rock colors range from N7 [Goddard et al., 1948] for heavily salt-weathered rock with no desert varnish, through 10YR5/4 for lightly varnished, 5YR5/4 for moderately varnished, to 5YR2/2 for heavily varnished resistant rocks. Areas between the rocks are occupied by gruss derived from the coarse-grained granitic rocks and silt probably deposited by the wind. The silt is lighter in color than the rocks (10YR7/4 - 5YR7/2) and consists of a vesicular A horizon. The topography of the surfaces consists of strongly developed ridges and swales about 5-10 m in wavelength and about 1 m or more in amplitude. The ridges are composed of

cobbles-boulders to 1 m, covering 50-60% of the surface and the swales are typically covered by about 20% of pebbles to cobbles to about 20 cm. These characteristics are interpreted to be caused by leveed debris flows, supported by the observation of boulder "plugs" in some of the swales [e.g. Whipple and Dunne, 1992].

The oldest unit on the alluvial fans is generally situated about 6 m above the intermediate unit and is recognized principally by the lack of exposed rocks (Fig. 4c). Rock relief is only about 1 cm and rock cover is about 30%, composed almost entirely of pebbles and flakes of fine-grained rocks with light to moderate varnish. Soil is mostly silt with a similar color (5YR7/2) as the silt on the intermediate unit. Stream cuts show that the lack of rocks is mainly the result of salt weathering in the upper 30 cm of the unit and to a lesser extent the deposition of a layer of silt up to about 20 cm thick.

The processes observed to be active on the alluvial fans of the Karakax Valley have produced distinct surface characteristics that can be discriminated and identified in the field and using remote sensing techniques. Specifically, 1) formation of desert varnish darkens rock surfaces; 2) salt weathering removes the varnished surface from some rocks, lightening the rock and 3) reducing rock relief by eroding the rock and depositing gruss at its base; 4) deposition of silt lightens the surface and 5) smooths the surface.

in contrast to the situation in the Karakax Valley, alluvial fan surfaces in the southern Great Basin of the western U.S. exhibit little salt weathering and thus develop and maintain a thicker, more complete desert varnish coating. Coarse-grained granitic rocks still disintegrate on these fans, although at a slower rate, allowing desert varnish to develop on bouldery intermediate surfaces. Finer-grained metamorphic rocks are very resistant, typically breaking down to a pebble-cobble size lag deposit. Deposition of aeolian silt is also common in the southern Great Basin; this silt works its way underneath the pebble lag, lifting it up and allowing the pebbles to settle into a low-relief stone pavement, present on the oldest surfaces [e.g. McFadden et al., 1987; Dohrenwend et al., 1991].

Conclusions

Geomorphic processes affecting alluvial fans in the Kun Lun Mountains of western China include the same processes affecting fans of the southern Great Basin of the US. These processes include aeolian deposition, desert varnish, and fluvial dissection. However, salt weathering is a much more important process in the Kun Lun. This decreases the effectiveness of desert varnish and prevents desert pavement from forming, since not enough resistant rocks are left to form a lag. ~'bus, the Karakax Valley signatures (Fig. 3a) are diagnostic of the dominance of salt weathering with secondary aeolian deposition while the Death Valley signatures (Fig. 3b) are indicative of the dominance of desert varnish and pavement processes. Remote sensing signatures are consistent enough in these two regions to be used for mapping fan units over large areas.

Remote sensing techniques are evolving to the point where calibrated measurements can be made that yield reliable estimates of geologically important characteristics such as surface roughness and composition over large areas. Process-response models of landscape evolution provide the necessary key so that these geological characteristics can be used to identify and map the stage of evolution of a surface. Future work in the Kun Lun area will use calibrated remote sensing signatures along with ages determined from measurements of cosmogenic nuclides in surface and near-surface rocks to estimate rates of processes important to remote mapping of alluvial fan surfaces in this region. Once these ages are better known, measurements of offset fan units will be used to determine the history of faulting along this segment of the Altyn Tagh fault [Peltzer et al., 1989].

Acknowledgments

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Figure Captions.

Figure 1. Location map showing the Karakax Valley (triangle) in the Kun Lun Mountains of northwestern China. The Altyn Tagh fault follows approximately the north edge of the Tibetan Plateau. Elevations from TerrainBase5' digital topography [Row and Hastings, 1994], overlaid with country boundaries and the swath center for SIR-C data take 175.31.

Figure 2. Remote sensing images of a Karakax Valley fan ($36^{\circ} 14' N$, $78^{\circ} 33' E$). Note Altyn Tagh fault bisecting fan, with left-lateral offsets and a pull-apart basin in the oldest unit. North up, images about 5 km wide. a) SIR-C image, L-band (25 cm wavelength), HH polarization, obtained 20 April, 1994. Note bright active wash in center, intermediate surface mostly to the west, and old dark unit to the east, b) French SPOT panchromatic image (copyright CNES). Note active unit is darkest and oldest unit is brightest.

Figure 3. Uncalibrated SIR-C (LH VV) and SPOT signatures of fan units. Vertical bars represent standard deviation of measurements made on several fans. a) Karakax Valley fans. b) Death Valley fans.

Figure 4. Field photographs of 3 main fan units in the Karakax Valley. a) Active unit. b) intermediate unit. Foreground boulders are about 50 cm across. c) Old unit. Intermediate surface is below at left.

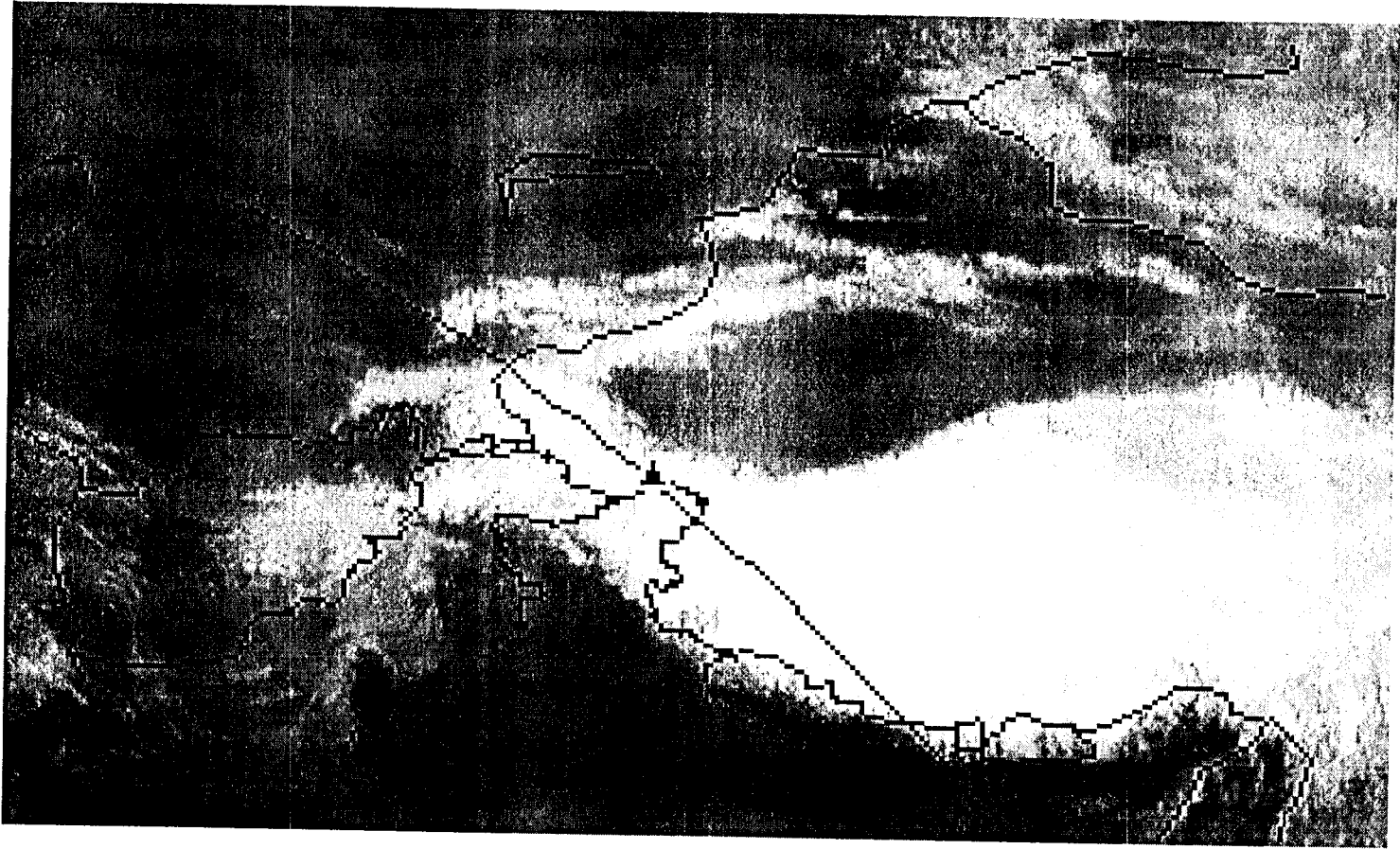
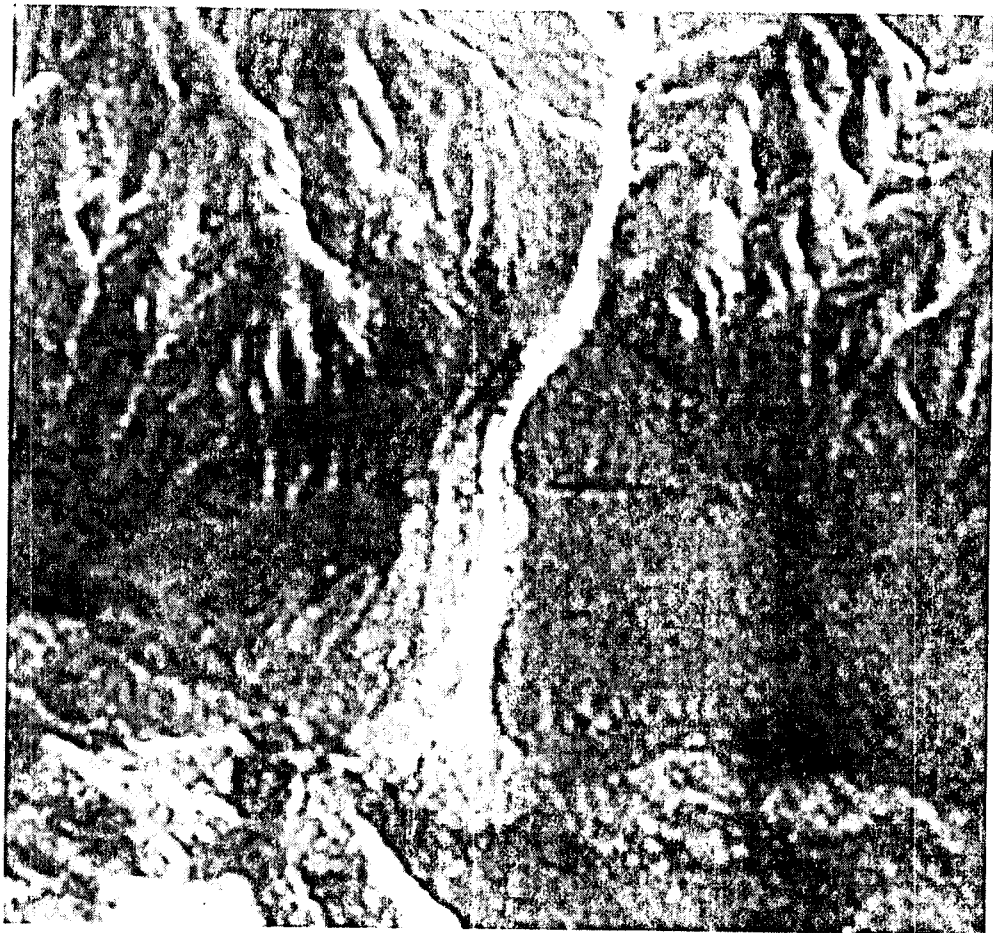
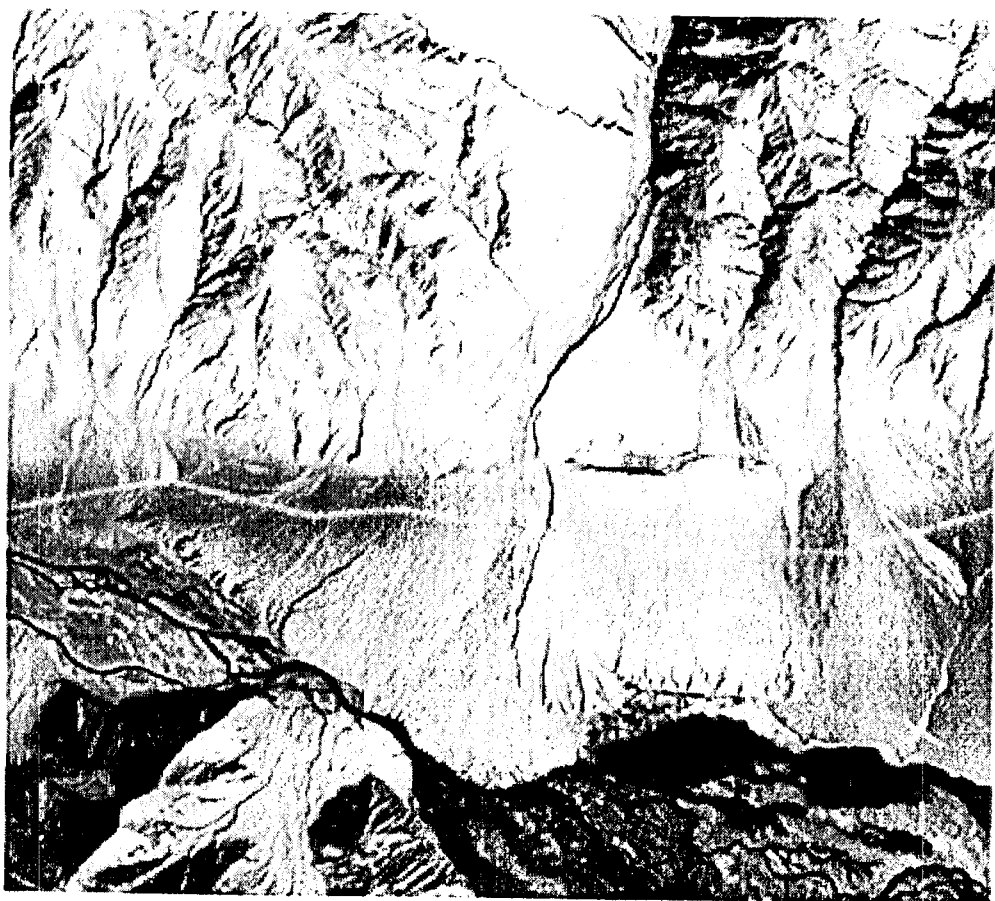


Figure 1. Farr: Geomorphic Process es...



a



b

Figure 2. Farr: Geomorphic Processes...

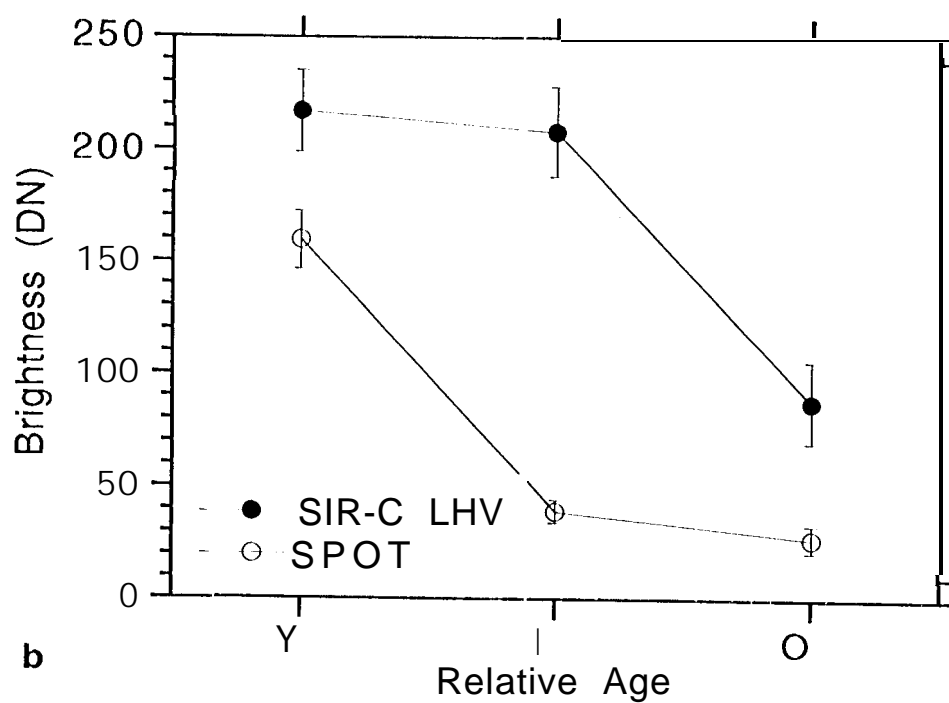
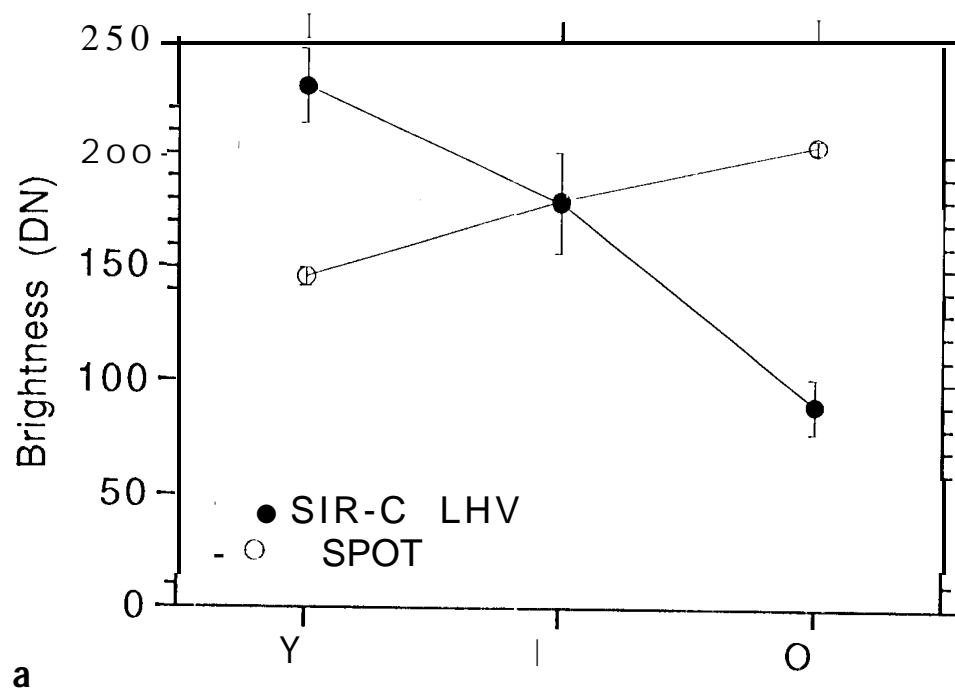
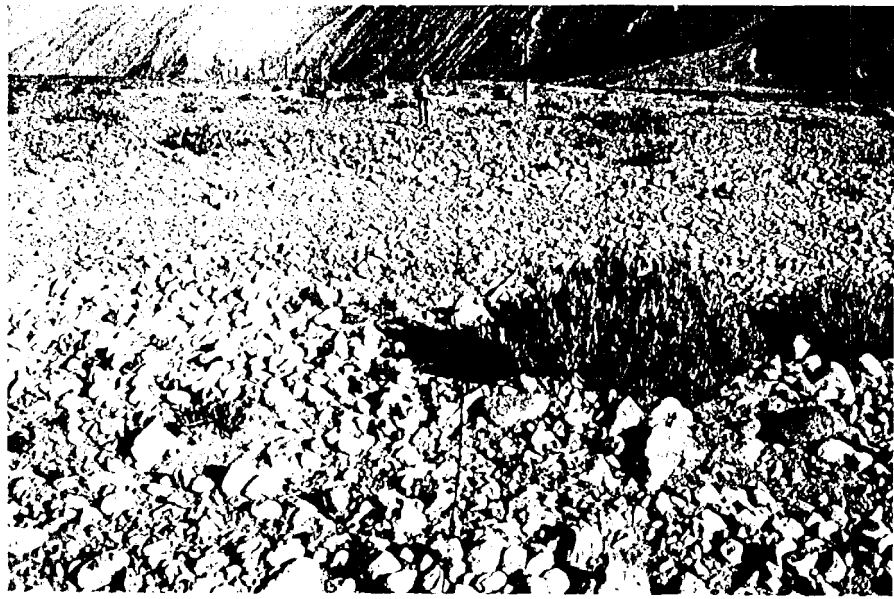


Figure 3. Farr: Geomorphic Processes...

a



b



c

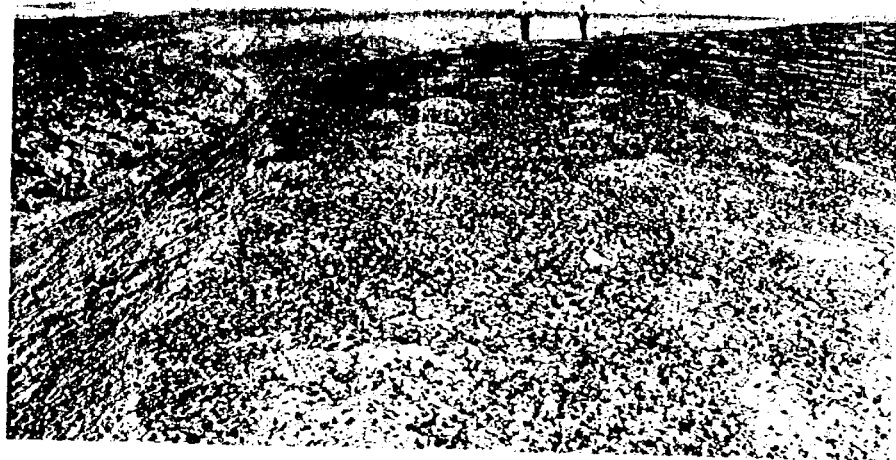


Figure 4. Farr: Geomorphic Processes...